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TEKSCOPE

Volume 9 Number 2 1977

TEKSCOPE

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Customer Information from Tektronix, Inc.,
Beaverton, Oregon 97077

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Contents

Cover: Software and prototype hardware are brought together and thoroughly checked using the 8002 Microprocessor Lab with optional Prototype Control Probe. The CT8100 Crt Terminal is also optional.


David Lowry


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The 8002—a new design tool for microprocessor users

The microprocessor is revolutionizing the way in which we design new products. In the microprocessor-based system, functions are created and stored in memory rather than on individual logic components. Design changes, then, often can be effected simply by substituting program instructions for hardware. Software thus becomes a significant factor in overall design.

While hardware and software design are usually undertaken as separate functions, they are accomplished most effectively when treated as a dynamic, interactive process. The capability of testing both hardware and software at intermediate levels of development greatly eases the task of final integration of the two.

A new kind of design tool has been developed to meet these unique design needs. In general, these tools are classified as microprocessor development aids (MDA's). Their function is to provide a working environment that closely approximates the real product environment the design team is trying to develop. The new TEKTRONIX 8002 Microprocessor Lab provides just such an environment.

Several important design goals were set for the 8002:

The user should not be limited to considering only one type of microprocessor for his design. All of the more popular types should be accommodated, with provision for adding new types as they become available.

The user's interface with the system should be simple and remain unchanged regardless of the processor under development.

The system should provide stand-alone program development capability (with the addition of a teletype or crt terminal).

The system should be useful in developing both software and hardware through interactive testing at successive levels of development.

The user should be able to accomplish final integration of the software and hardware in a smooth, efficient manner.

Multiple microprocessor architecture

To achieve these goals, the tasks to be performed by the 8002 have been divided into three functional areas. A separate microprocessor is used for each area. Those related to the development system are assigned to a *system* processor; those related to program assembly are assigned to an *assembler* processor; and prototype-related tasks are assigned to an *emulator* processor. The system and assembler processors are common to the development system, while the emulator processor is identical to that which will be used in the prototype being designed.

To develop programs for a particular type of microprocessor requires installing a plug-in circuit card containing the selected microprocessor, in the 8002 Mainframe, and inserting a diskette, with the appropriate assembler software, into the dual flexible disc drive. Two emulator processors can be housed in the 8002 Mainframe at the same time and invoked individually from the system console.

Initially the 8002 supports the 8-bit 6800 and 8080, and the 16-bit TMS 9900 microprocessors. Z80 support will be available late this summer, with more to follow.

Now let's look in greater detail at the functions performed by each of the microprocessors resident in the 8002.

The *system* processor performs all of the system services that are not prototype-dependent, such as:

System Input/Output—directs all I/O activity for the 8002 system peripherals, such as the flexible disc, the console, and the line printer.

File Management—organizes, stores, and retrieves user programs and system programs from the disc drives.

Text Editing—executes the text editor program and maintains text files on the Flexible Disc Unit.

Debugging—executes the debugger program and controls the emulator processor through separate debug hardware.

System Utilities—performs all system utility functions such as processing the messages between system peripheral devices.

PROM Programming—monitors and controls all PROM (Programmable Read Only Memory) activity.

The *assembler* processor, with the appropriate diskette inserted in the flexible disc driver, performs program assembly functions for each of the microprocessors supported by the 8002. The assembler hardware is universal, requiring only software changes to assemble programs for different types of microprocessors. The Assembler runs in 16k of Program Memory, and uses any additional Program Memory for symbol tables.

Fig. 1. The 8002 Microprocessor Lab with optional CT8100 Crt Terminal.

The third processor in the multiple-processor architecture is the optional *emulator* processor. It is used in program debugging, emulating the target microprocessor, and integrating the software and hardware into a finished product. Used with the Prototype Control Probe, which connects the 8002 with the prototype, the emulator provides for progressive levels of software/hardware testing and integration.

Each of the three microprocessors—system, assembler, and emulator—occupy individual plug-in circuit board modules in the 8002. In addition, there are System Memory, Program Memory, Systems Communications, and Debug and Front-Panel I/O modules resident in the 8002. The remainder of the capacity can be filled with options, such as the Real Time Prototype Analyzer, PROM Programmer, or additional Program Memory.

The bus structure

The system architecture includes a 100-line bus structure to tie system components together and permit the exchange of data and control signals. The bus is essentially universal in that data, address, and control lines are paralleled to all boards. The exceptions to this structure are the independent debug control and interrupt lines for the system and emulator processors (See Fig. 3.).

The system processor services the peripheral I/O devices and debug logic with a hierarchy of interrupts. All I/O services are performed by the system processor.

The memory structure

In keeping with the multiple-processor architecture, the memory system in the 8002 is also segmented. The random-access memory consists of two major sections—a 16-kilobyte *system* memory and a 16-kilobyte *program* memory. The program memory can be expanded to 64 kilobytes, in 16-kilobyte increments, by adding plug-in memory modules to the 8002.

Also resident in the system memory is a 256-byte ROM that performs a bootstrap function for system initialization. A dual flexible disc system, supplied as a standard part of the 8002, provides approximately 660 kilobytes of on-line mass storage.

The system memory is accessed only by the system processor and contains TEKDOS (the operating system software). The main, resident part of TEKDOS is transferred into the system memory RAM at start-up, with subroutines loaded from the system disc as needed. The system memory also provides buffer space for I/O activities.

The primary purpose of the program memory is to store the user program during execution by the emulator processor. It also provides working space to the system and assembler processors during program assembly and editing activities.

The disc operating system

TEKDOS, the overall operating system previously referred to, contains the supervisory monitor program for the system. Other components of TEKDOS include the Text Editor, Assembler, Linker, emulation support routines, Debugger, and PROM Programmer. Utility routines allow the user to create files, list disc file directories, maintain discs, and delete files.

Under the control of TEKDOS, you can prepare a program using the text editor, correct and modify it quickly and easily, assemble it, load the resulting object

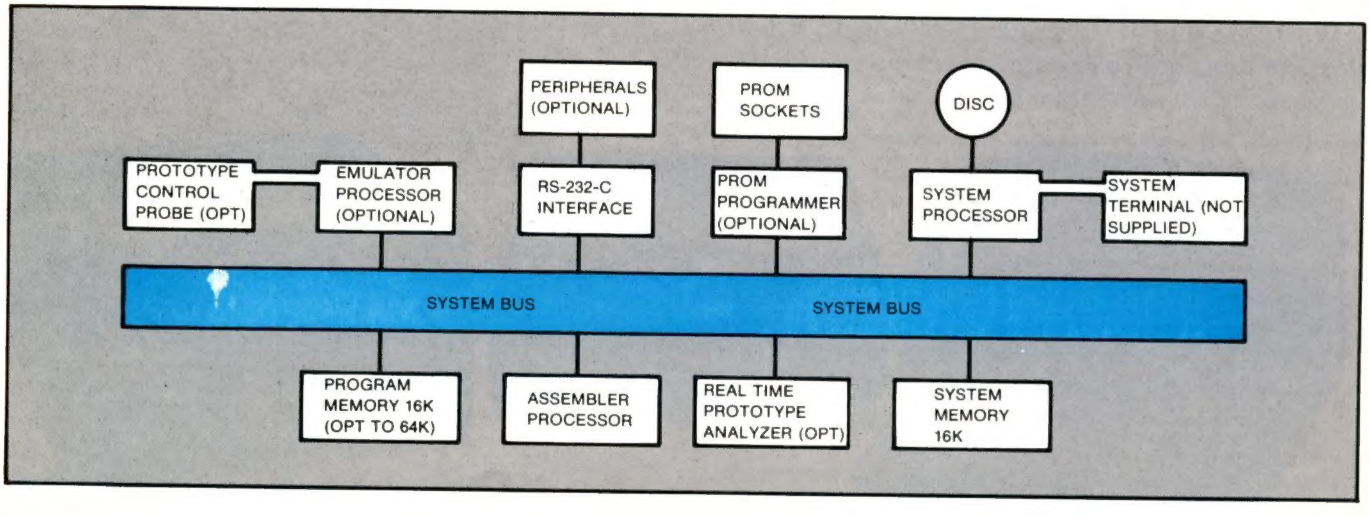


Fig. 2. Simplified block diagram of 8002 system components. Multiple processor emulators and up to 48 kilobytes of additional program memory can be accommodated in the 8002 mainframe.

code into program memory, and cause it to be executed under debug control.

During execution, the program steps can be traced, breakpoints can be set, and memory can be inspected and altered as required. The program can be corrected or modified at the source level, using the text editor, then reassembled, loaded and executed again for further debugging if needed.

The emulator processor

Once you have the program developed (or a module of the total program) you will need to test it on the hardware with which it will be used. The emulator processor and prototype control probe provide this capability.

The prototype control probe consists of a cable, appropriate interface circuits, and a 40-pin (depending upon the type of microprocessor) connector that plugs into the microprocessor socket on the prototype circuit board. The 8002 end of the cable connects to the emulator processor circuit board.

The prototype control probe allows the 8002 emulator processor and program memory to substitute for the prototype microprocessor and its associated memory. The system console provides the I/O functions normally supplied by the prototype.

Now the user program can be run, tested, and debugged using successive levels of integration with the prototype hardware.

Three levels or modes of emulation are available to you: in the System Mode, the emulator processor runs the user program residing in the 8002 program memory; the 8002 I/O signals are also used. This is essentially a non-emulation mode since we are not using any circuitry in the prototype.

The second mode, called the Partial Emulation Mode, uses the emulator processor to run the program residing in the 8002 program memory, but all I/O signals and data are supplied by the prototype hardware.

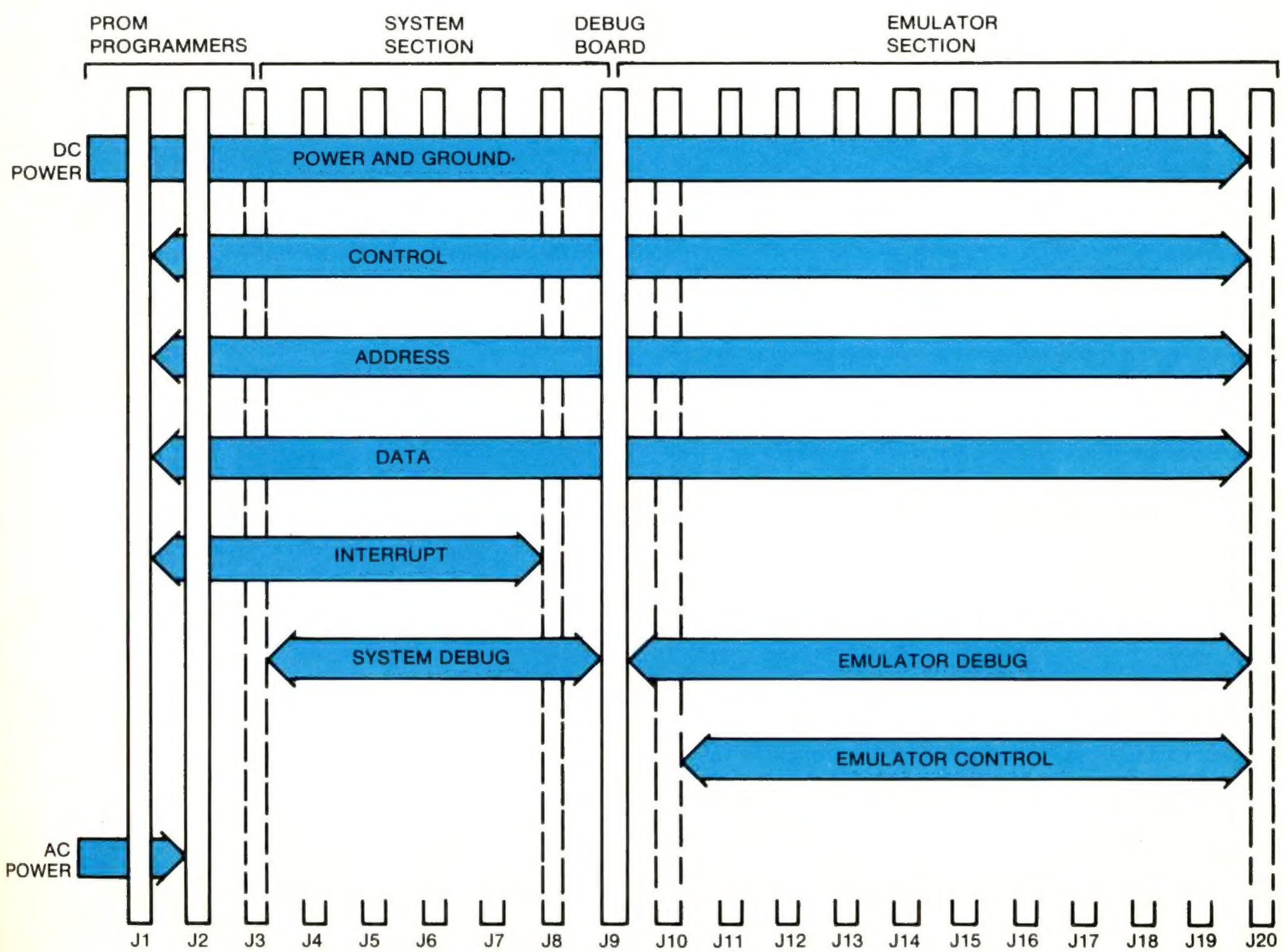


Fig. 3. Flexibility and expandability are afforded by the 100-line bus structure that ties the system components together. Up to 20 plug-in circuit boards can be housed in the 8002 mainframe.

The debugger system

One of the most powerful elements in the 8002 Microprocessor Lab is the debugger system. A subsystem of TEKDOS, the debugger resides on flexible disc and is transferred into system memory and executed by the system processor.

The debugger routines can be used to locate and analyze faults in both software and hardware from the early stages of their development through final integration of the two.

In the multiprocessor architecture of the 8002, the system processor cannot directly access the emulator processor's registers or the prototype hardware system. There is, however, a unique communications route enabled by the debugger in accomplishing its functions (see Fig. 1).

While the system processor cannot directly access data in the emulator processor, it can directly access program memory. The system processor transfers a portion of object program data from program memory into system memory. This space can now be used for storage of the emulator processor registers. The system processor then transfers control to the emulator processor which in turn stores its register contents in the space left vacant in the program memory. The system processor again takes control and accesses the data in program memory, thus allowing you to examine or modify the data by invoking the debugger commands. The procedure is reversed to restore the data to the emulator processor registers and program memory.

The prototype's memory contents can be accessed in a similar manner via the prototype control probe.

The Debugger commands

There are seven commands in the debugger's command repertoire, and several TEKDOS commands that are legal while the debugger is active.

Executing the DEBUG command causes the debugger to be loaded into system memory and initialized. The debugger allows you to enable or disable program execution monitoring with the TRACE command. The TRACE command may be invoked in three forms: TRACE ALL, TRACE JMP, or TRACE OFF. After either of the first two has been invoked, a trace line will be displayed on the display device specified in the DEBUG command when the specified program instruction or instructions are executed. The trace line contains one line of program execution, along with information pertaining to the executed line.

In the TRACE ALL form, you can single-step program execution, examining every instruction's trace line, display trace lines for a selected group of instructions, or display all of the trace lines as the program is executed, and stop execution at any desired point.

If you specify TRACE JMP, only jump instructions in the program's execution sequence will have their trace information displayed. You may select single-step or multi-step operation as in the TRACE ALL form. The TRACE OFF form disables all trace display.

The DSTAT command displays the current status of the debugging session. When this command is invoked, a display line which includes the emulator processor's last instruction address; the active breakpoints and the breakpoint's parameters; and the emulator's stack pointer, flag register, and register contents; is sent to the debug display device. The DSTAT display format varies somewhat, depending on the type of microprocessor under development.

When read and write operations are performed within program execution, you may monitor their effects by suspending execution with breakpoints. Breakpoints are set and cleared by the BKPT and CLBP commands, respectively. The BKPT command will cause program execution to be suspended after a read or write operation has been performed at a specified address location. When a breakpoint is encountered, a trace line of the instruction where the break occurred is output to the display device. Up to two breakpoints may be set at one time.

The SET command allows you to reassign hexadecimal values in the emulator processor's registers. All registers, or any contiguous group of registers, may be reassigned values.

The RESET command, as the name implies, allows you to reset the emulator processor's hardware to a known beginning state. This command is useful if the hardware enters an unknown execution state. These seven DEBUG commands, in conjunction with the applicable TEKDOS commands, allow you to execute the user program under control of the systems processor, and quickly and easily make any needed changes.

After you have debugged the software, using the emulator processor in the 8002, you are ready for the real test—seeing if the program will run on the prototype hardware. This is accomplished using the optional prototype control probe and real time prototype analyzer as discussed in the main body of this article.

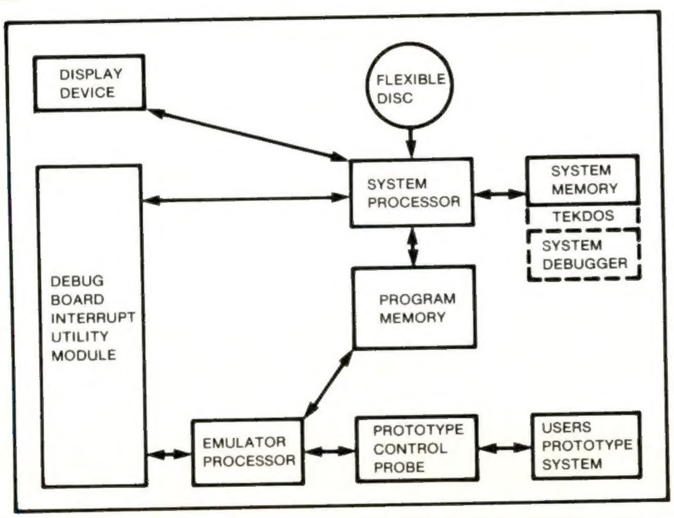


Fig. 1. Program memory, emulator processor register, and user prototype memory contents are made available for examination through this unique communications route.

In the Full Emulation Mode, the emulator processor runs the program residing in the external prototype memory. All I/O signals and data are supplied by the prototype, but supervision of the program is exercised by the 8002. Most of the debug capabilities, such as full trace, breakpoint, and single step are still available to aid in locating problem areas.

The program can be run at the speed with which it will actually operate in the hardware, so any problems with functions involving critical timing relationships can be uncovered.

The real-time prototype analyzer

At this point in the product's development, another important feature of the 8002 comes into play. The optional Real-Time Prototype Analyzer serves, in effect, as a logic analyzer with hardwired probes at the important pins on the prototype microprocessor socket. This enables you to acquire signals on the address, data, and control lines, and store them in a special high-speed buffer memory on the Real-Time Prototype Analyzer board.

A TEKTRONIX P6451 Logic Analyzer Probe is an integral part of the option, and provides eight lines for viewing logic signals anywhere on the prototype board. The P6451 plugs into the back of the 8002.

The Real-Time Prototype Analyzer is programmed from the 8002 system console, which also serves as the display device for the high-speed buffer. With the program running at maximum speed, you can stop the action at a selected address or instruction, and display the contents of the high-speed buffer in a properly formatted manner. You can cause every transaction to be stored and displayed, enabling you to quickly locate and analyze problem areas.

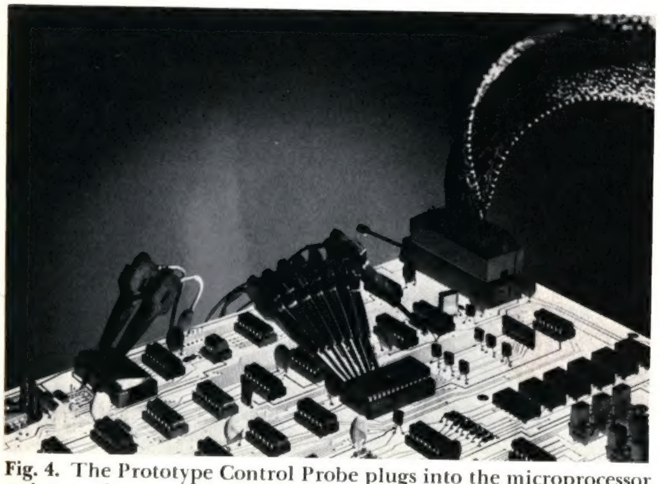


Fig. 4. The Prototype Control Probe plugs into the microprocessor socket on the prototype circuit board. Real-time prototype analysis for monitoring logic transactions in the prototype is accomplished with real-time trace and the 8-channel analyzer probe.

The PROM programmer

Once you have debugged the user program and tested it with the prototype, you are ready to commit it to

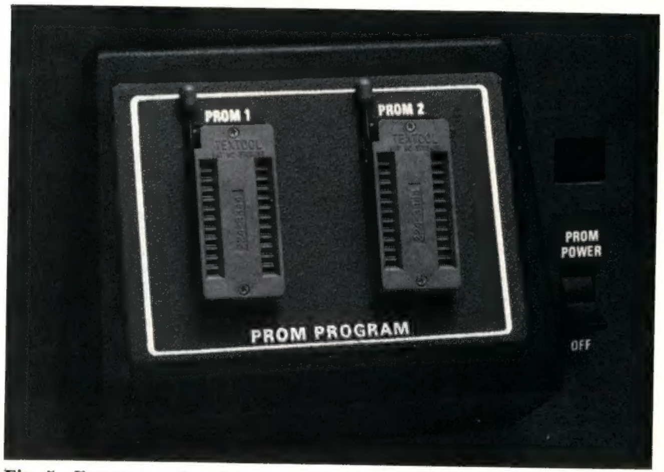


Fig. 5. Front-panel sockets provide for convenient programming of 1702 or 2704/2708 MOS uv-erasable PROMs with the optional PROM programmers installed in the 8002.

PROM. A plug-in option for the 8002 lets you complete this important step in the design process, without having to invest in a separate PROM programmer.

At present, the 8002 supports two different PROM programmers for ultraviolet-erasable PROMS—one type for 1702A PROMs and another for 2407/2408 PROMs. Two PROM sockets are available on the front-panel of the 8002.

With the PROM Programmer option installed and a PROM chip plugged into the appropriate front-panel socket, TEKDOS commands can be executed from the system console to transfer user programs from the 8002 program memory into PROM. Or the reverse action can take place—the contents of PROM can be read into the program memory. In addition, the user program residing in PROM can be compared with the user program residing in the 8002 program memory. The differences are then displayed on the system console, providing a fast and accurate verification of the PROM contents.

Summary

The 8002 Microprocessor Lab with its extensive choice of options provides you with a versatile new tool for designing microprocessor-based products. Every step of the process, from entering source code to burning the finished program in PROM and final integration of hardware and software, can be accomplished in an effective, efficient manner.

As new microprocessors become available, the 8002 can be easily adapted to them by the addition of a plug-in emulator processor board and flexible-disc-based software.

Support for the 8002 is provided by Tektronix' worldwide network of field offices and service centers.

The 8002 will be introduced outside the United States at a later date. For further information please contact the nearest Tektronix Field Office, Distributor, or Representative.

Bruce Rodgers

The fundamental beauty of computer graphics

Computer users are becoming increasingly aware of the utility of graphics, applying them in many new areas. Traditional applications have been mainly engineering drawing, such as circuit design, drafting, and mapping, while the newer applications include data representation, i.e., presenting data which are not inherently graphical or geometrical. Presenting management information is becoming a major field for computer graphics. In a recent survey, Datapro determined that 53% of the respondents (current graphics users) have primary applications concerning the presentation of business or scientific data as opposed to interactive design of geometrical objects.[1]

Businessmen, scientists, and engineers are recognizing that graphics can communicate ideas more rapidly and clearly than a table of numbers. This is particularly true when describing a situation to people not familiar with the application. An engineer has fewer requirements when studying the results of his own computations, but to present technical, financial, or organ-

izational information to an individual not conversant with the application area to begin with requires presentation methods that are clear, concise, and immediately obvious. Graphics are being used increasingly for management reporting as well as reports to customers, investors, and others outside of the company. The need for clarity is the same in both cases; the aesthetic requirements are usually greater when relating to outsiders – but with modern technology, computer graphics is a feasible tool for both kinds of applications.

The rapid growth in the number of cost-effective graphic devices being offered, from cathode ray tube (crt) terminals to plotters, means working graphics are available for internal applications such as "war rooms," management reports, and proposals, as well as traditional engineering drawings. At the same time, modern high level software is capable of producing publication-quality graphics, and still reducing the programming effort to make "running off a plot over lunch for this afternoon's meeting" a practical proposition.

Wise resource utilization

Since their conception decades ago, computers have enjoyed an incredible expansion of applications. There has been a number of parallel evolutionary developments which have revolutionized utilization methods and permitted this expansion. Some of those trends are indicated in Figure 1.

The most significant new developments serve as amendments rather than replacements of earlier methods. The obvious example, which applies to graphics as well as other areas, is the evolution of interactive problem solving.

The fastest way to develop graphic output is using an interactive graphic terminal, or an alphanumeric terminal with a plotter attached to it. Since time is often the main expenditure during development of any application, fast work often overrides other considerations. For production runs, however, batch operation provides alternative economies and permits the highest quality output. Modern graphic software permits the use of different devices with the same program, reaping the benefits of both environments.

Higher level languages are replacing assembly level programming and, similarly, high level graphics systems are replacing the old line-by-line, pen command-by-pen command systems. Many users still remember the day when making a simple axis for a diagram was a one day project. With a modern high level system the user no longer must issue pen movement commands, but assemble and polish a working plot into a professional representation.

When the graphics are to be published – in a magazine, technical journal, report, or brochure – quality becomes an economically important issue. Traditional computer graphics always needed manual reworking, and thus combined the worst of two worlds: the programming effort and cost of computer operation, and the cost, turn-around time, and lack of reliability of an art department professionalizing the graph. With modern graphics, the ordinary graph can be transformed into publication-quality, camera-ready output with a few commands. It is a waste of precious resources to have a key manager, technician, or administrator spend days producing high quality output, *after* the computer program has been run.

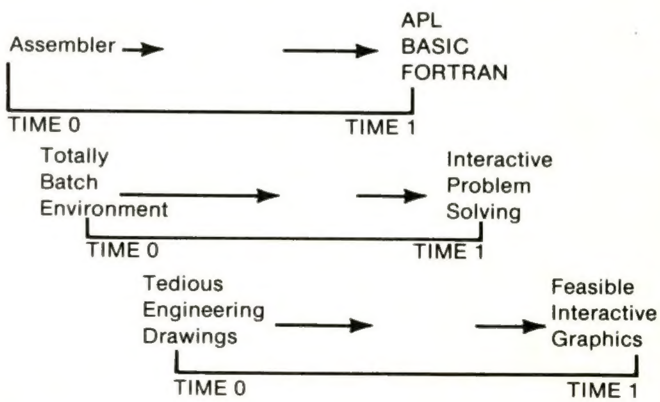


Figure 1

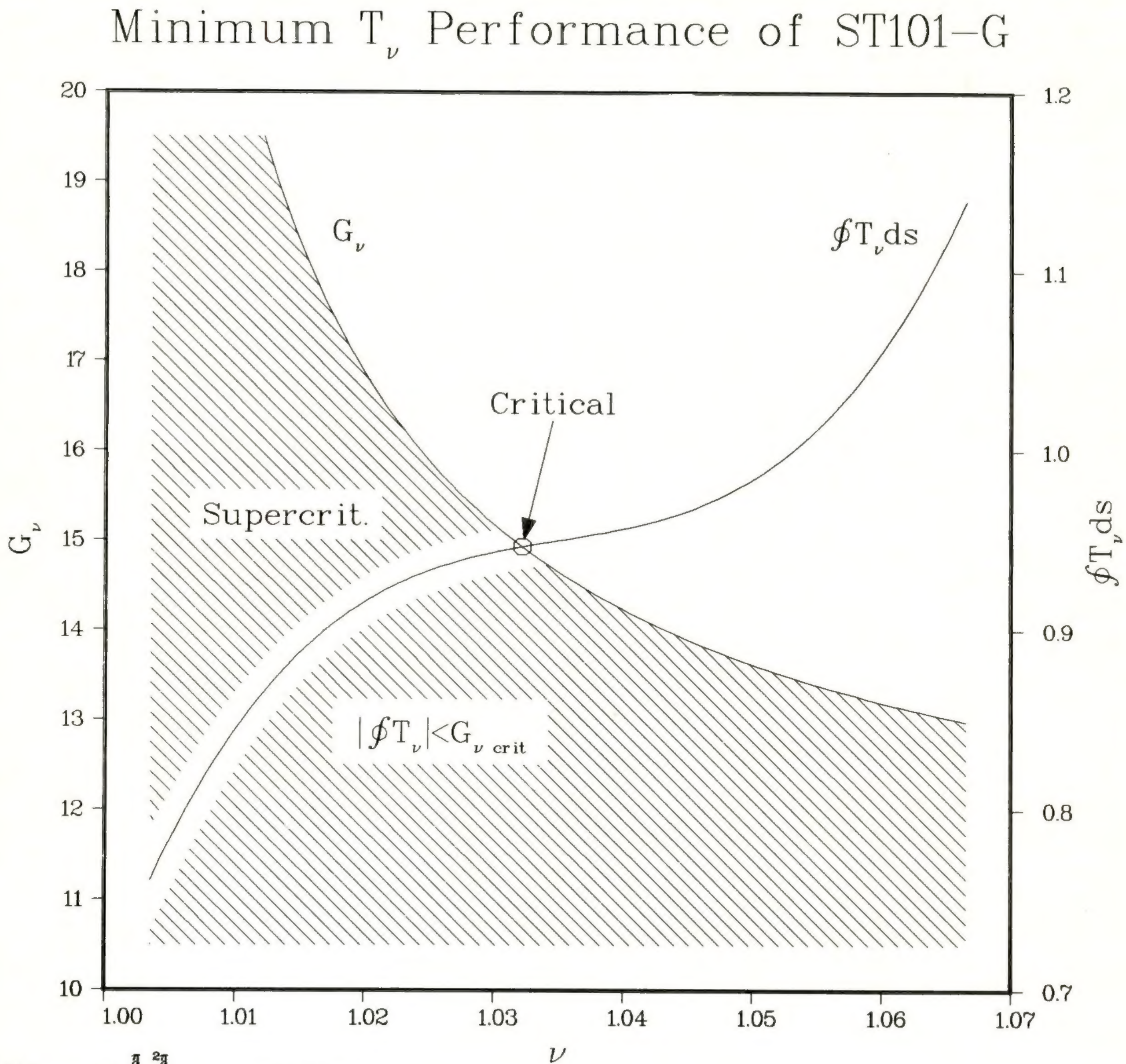
Figure 2 on page 10 illustrates some of these notions and the quality attainable. (Note: none of the illustrations in this article have been edited in any way, including the formulas of Figure 2 and the heading of Figure 6. The graphs come directly from a medium quality plotter) .

Graphics are "friendly" tools

A major cause for concern to the systems manager is the man-machine interface, especially when users are non-technical. If graphics are to be a feasible output medium, as practical and immediate as the printer, they must be available to users other than the graphics expert.

A major innovation in the computer industry was the development of the storage crt. It has proven itself as the most productive tool for interactively building, previewing, and using graphic output in many application areas. The speed and high picture quality of a storage crt terminal makes it a very pleasant device to use, and the low cost of modern terminals, comparable to alphanumeric terminals, makes them available to more and more users.

The minicomputer and other advancements of electronic and mechanical technology have made the small



$$\begin{bmatrix}\xi_P\\ \eta_P\end{bmatrix} = \frac{\csc 1''}{2\pi\gamma R^2}\int_{\psi=\psi_0}^{\pi}\int_{\alpha=0}^{2\pi}\Delta g(\psi,\alpha)V(\psi)\begin{bmatrix}\cos\alpha\\ \sin\alpha\end{bmatrix}R^2\sin\psi\, d\psi\, d\alpha$$

Figure 2

bed plotter a very cost effective device for generating hardcopy of high quality.

These devices have been used for many years, and a substantial amount of device-specific support software has been written. Therein lies a major problem. Systems managers are well aware of the trauma involved in recoding earlier application programs to adapt them to new devices.

Previous graphics experience often precludes taking advantage of new hardware and firmware developments.

Field-proven, device-independent software exists (such as ISSCO's DISSPLA package), that reduces adaptation of new devices to one or two lines of code.

Modern software is also designed to make all possible assumptions without user intervention, making a simple standard plot attainable with minimum effort (in some cases a single line of code providing the data). At the same time, enhancements tailoring the graph to specific needs may be added with simple task-oriented commands, permitting the expert virtually unlimited flexibility.

UNADJUSTED SALES VOLUME
Dept. M-19 and M-21

1970	12469
1971	23609
1972	20120
1973	30964
1974	27311
1975	44608
1976	34901

Figure 3 A confusing table

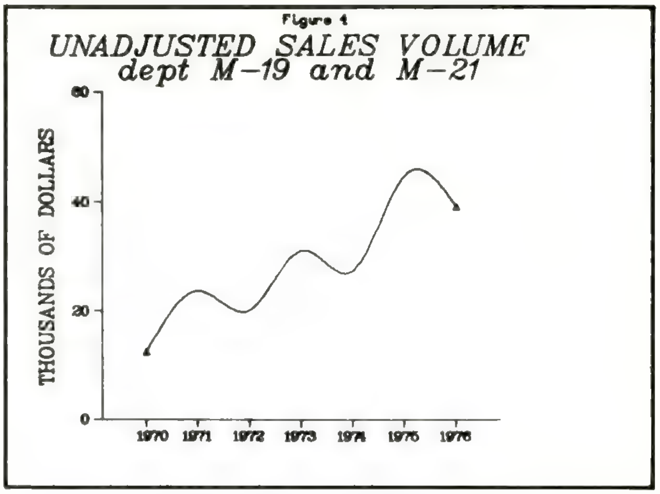


Figure 4

Lists and tables translate into useful graphics

The most common responses from users asked "Why computer graphics?" refer to the difficulty of reading and understanding tables and listings. Does your EDP operation provide truly usable — immediately usable — management information? Does the computer output still confuse you, or do answers leap off the page? Computer graphics can effectively reduce data to more easily understood means.

A classical example of the confusing power of a table is illustrated in Figure 3.

The immediate reaction when confronted with this table is to look to the bottom lines and conclude that a drastic decrease in sales volume occurred in 1976. However, the simple plot in Figure 4 shows the cyclic variations on a long-term strong positive trend, thus providing the manager with better information.

Many businessmen use trendlines and statistical methods to reduce the data volume. This does not always produce understandable results — a simple plot of the data and trendline illustrates variance and systematic behavior of the data with superior clarity. In many cases the data do not easily lend themselves to statistical analysis, e.g., Figure 5. In many cases, tables (with specific data points) and plots are complementary.

The problem becomes even greater when examining the behavior of one variable as a function of two others. This is a common situation, and tables can be cumbersome. Even ordinary two-dimensional graphics, X-Y diagrams, often will not suffice; 3-D graphics are needed. Note that we are still talking about data representation graphics, not drawings of three-dimensional objects (e.g., piping diagrams or airplane structural drawings).

The 3-D plot is illustrated by the personnel data in Figure 6. It depicts the distribution of employees of the ACME corporation as a function of age and seniority. The large number of young people who stay only a year is evident, and the high turnover rate of unskilled labor is probably a well-known problem to the personnel department. However, the lack of people in the age bracket 45-50 with 10 years of experience, shown by the "hole" (see arrow), is possibly an unknown problem. These people joined the company at age 30-35, with significant outside experience and training, and it is from this group ACME will want to recruit its top technical management. Because of the shutdown of the research department in 1960 there is a lack of people in this category, and ACME may not have an adequate management pool from which to draw future managers.

The "hole" is clearly visible on the 3-D plot, but it is not shown on the "walls," because the hills surrounding the hole mask it. A table of numbers does show the problem, but it may be detected only after careful and imaginative study, or if the manager had prior knowledge of the potential problem. Only the 3-D plot highlights the significant features of the data, and "hides" the uninteresting variations as ripples in the surface.

Most of our education and experience is oriented towards two-dimensional plots, since they can be done by hand. The 3-D plot has become a feasible tool only with the advent of the computer and high level software. The number of applications, however, is increasing rapidly as users become aware of the capabilities.

Modern graphic software provides full control over a 3-D plot, with any viewpoint and scaling, with half a dozen commands. A 3-D plot is a reasonable standard output form. Rather than producing a 3-D plot to present a problem already detected, users are examining different combinations of data strings to test for informative spatial relationships (such as the ACME Personnel Plot).

Application examples

At the Bureau of the Census, users have employed Tektronix terminals since 1972, and DISSPLA since 1974, to generate quality computer graphics. Of the wide variety of applications addressed at the Bureau, Mr. Larry Cornish's group in Systems Software Division renders the graphics for a monthly chartbook of social and economic trends. This publication contains the vital census statistics, including population projections, GNP, Industrial Production, birth rate trends, and unemployment.

DISSPLA resides in a system that includes Univac 1108s and 1110s, where 50-100 people access the package regularly. The users are clerks, statisticians, cartologists, mathematicians, and economists. The Bureau provides not only neat, clear graphs but *accurate* graphs. Concern for aesthetics and accuracy is high.

Because of their publication orientation, DISSPLA offers in one package the tools required for quality, accurate graphic output, including mapping routines, 3-D perspectives, statistics, and the ability to go clear to typeset, accessible by all of the on-site equipment. Tektronix equipment employed by the Division includes 4012 and 4014 Computer Display Terminals and 4051 Graphic Computing Systems.

Programmers are no longer directly involved. A master command language prompts users interactively and allows them to walk through their application programs without requiring a great deal of programming expertise.

Argonne National Laboratory has been using Tektronix graphic terminals and the DISSPLA package for almost four years on IBM 360 and 370 systems. DISSPLA was attractive to them because of its device independence and because of the superior documentation that accompanies the package.

Again, many and varied applications are supported by the Tektronix and DISSPLA package. Those applications include mapping, environmental sciences, and many business-related graphs.

Mr. Robert Clark of Argonne's computer graphics group estimates that about one half of the 1500 member scientific staff have used their facilities, and computer graphics usage continues to grow. Currently over 6000 jobs per month requiring graphic output are processed.

The fundamental beauty of graphics is now feasible

Computer graphics are revolutionizing computer usage as one of a number of evolutionary developments in computer usage. Graphics can fill in one side of the oft-dreamed-of man-machine interface which permits non-experts to use computers. The output at least is now more humanized, and only minimal expertise is needed to provide the input. Systems which permit non-programmers to specify their graphics requirements in plain English are under development, and the next phase of modern software will employ conversational code (English sentences on the crt).

The concurrent evolution of sophisticated graphics software and low cost, quality hardware have made the fundamental beauty of immediate and powerful graphic output economically and practically feasible.

A special note of thanks to Anders Vinberg, Technical Marketing Consultant, Integrated Software Systems Corporation (ISSCO), for his valuable contributions to this article.

Plots are courtesy of Integrated Software Systems Corporation.

[1] "All About Graphic Display Devices," February 1977, Datapro Research Corp., Delran, N.J. 08075.

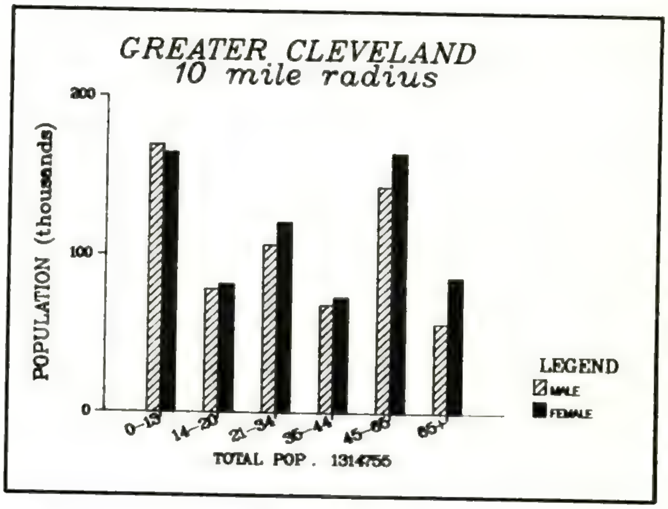


Figure 5

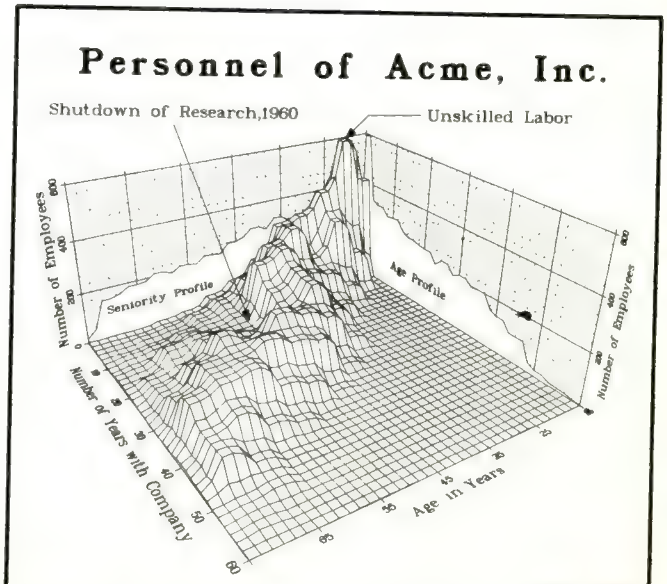


Figure 6

Ken Matheson

Measuring harmonic distortion with a spectrum analyzer

Frequently you may be required to measure the harmonic distortion, or as it is sometimes called, harmonic content, of an amplifier or signal source.

The harmonic distortion of a sine wave signal is defined as "the ratio between the amplitude of the fundamental frequency and the RMS sum of all the harmonic amplitudes." Harmonic distortion is usually expressed as a percentage, while harmonic content is generally expressed as being greater than so many dB down from the fundamental.

There are many methods and different types of test equipment that can be used to make distortion measurements. They vary widely in cost, frequency range, accuracy, user convenience, etc. One of the more versatile instruments used for this function is the spectrum analyzer, especially for frequencies in the megahertz or gigahertz range.

While distortion analyzers are often used for measurements in the audio range, low-frequency spectrum analyzers can yield similar accuracies and provide details on the harmonic content of the signal.

Harmonic distortion or THD (total harmonic distortion) is determined by measuring and summing the amplitude level of the various harmonics contained in a sine wave signal. The charts in figures 1 and 2 provide a quick, easy means of computing harmonic distortion from a spectrum analyzer display.

Let's consider the display in figure 3. The signal is a 10 kHz sine wave generated by the TEKTRONIX FG 504 Function Generator. The vertical deflection factor of the display is 10 dB per division, and horizon-

RATIO in dB	% of READING	RATIO in dB	% of READING
20, (40; 60)	10% (1% .1%)	30, (50, 70)	3.16% (.31, .031%)
21	8.9	31	2.87
22	7.94	32	2.51
23	7.08	33	2.24
24	6.31	34	2.00
25	5.62	35	1.78
26	5.01	36	1.59
27	4.47	37	1.41
28	3.98	38	1.26
29	3.55	39	1.12

Fig. 1. Chart for conversion from dB's to percentage readings.

dB DIFFERENCE	ADD TO HIGHER LEVEL	dB DIFFERENCE	ADD TO HIGHER LEVEL
Same (OdB)	3.01	5	1.19
1dB	2.54	6	.97
2	2.13	7	.79
3	1.76	8	.64
4	1.46	9	.51

Fig. 2. Correction factors for addition of frequency components.

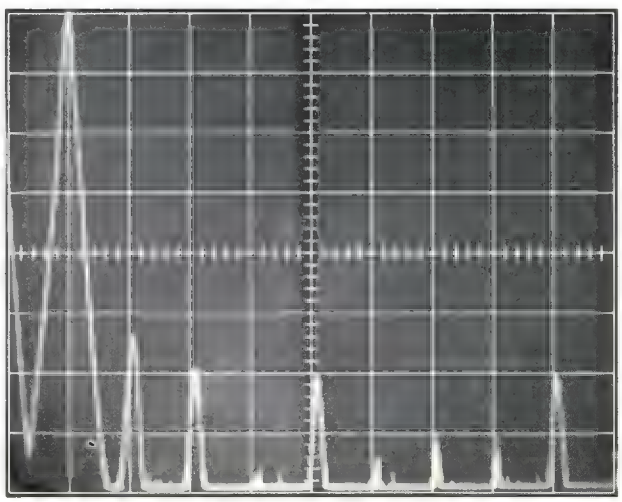


Fig. 3. A display of a 10 kHz sine wave signal containing 0.237% harmonic distortion. Vertical deflection factor is 10 dB/div and horizontal scan is 10 kHz/div.

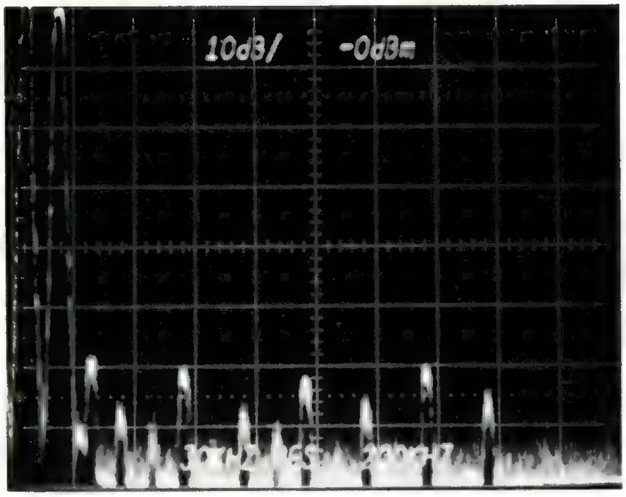


Fig. 4. A 100 kHz signal containing 0.194% harmonic distortion. Three of the higher order harmonics are less than 6 dB down from the 2nd harmonic and must be considered in the calculation.

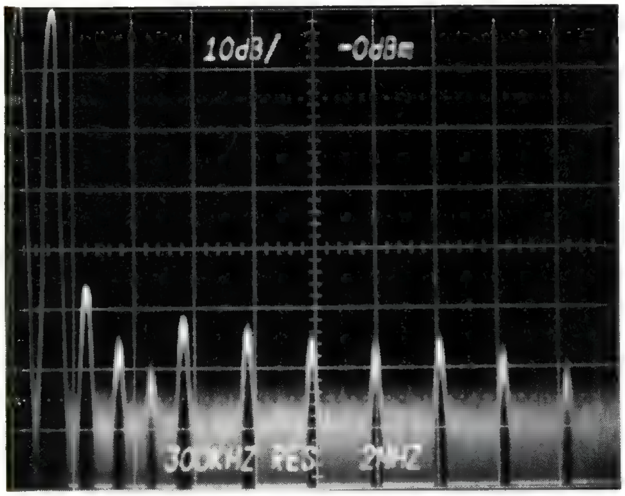


Fig. 5. A 1 MHz signal containing 0.56% distortion. Only the 2nd and 5th harmonics need to be considered in the calculation.

tal scan is 10 kHz per division. We see that the second harmonic is 54 dB down from the fundamental, which gives us a distortion factor of 0.2% (from figure 1). To get a more accurate measurement of total harmonic distortion, we should include in our calculations the affect of any higher order harmonics that are less than 6 dB down from the second harmonic. The third harmonic is 5 dB down. From the chart in figure 2 we note that a correction factor of 1.19 should be added to the second harmonic level of −54 dB. The resultant is −52.8 dB which corresponds to 0.237% distortion (from figure 1).

As a rule of thumb, we can ignore harmonics that are greater than 6 dB down from the second harmonic. The fifth harmonic is 7 dB down from the second; let's see how it affects our distortion reading. From the chart in figure 2, we find a correction factor of 0.79 should be applied to the third harmonic amplitude. The resultant amplitude is −58.21 dB. The difference between the

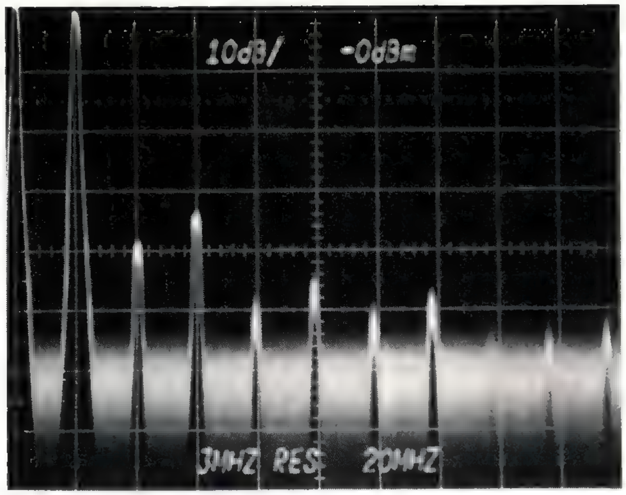


Fig. 6. In this 20 MHz signal, the 3rd harmonic is the major contributor to distortion. The combined effect of 2nd and 3rd harmonics results in 2.5% harmonic distortion.

second and third harmonic is 4 dB, and referring once again to figure 2 we find a correction factor of 1.46 which is to be added to the second harmonic amplitude. The resultant is −52.54 dB. Referring to figure 1 we see this corresponds to a distortion factor of 0.238%, almost identical to that obtained when we ignored the fifth harmonic.

To determine how closely the distortion factor obtained from the spectrum analyzer display correlated with that measured on a distortion analyzer, we applied the same signal to an HP 334A. The result was the same. Comparing measurements at other frequencies, we found a high degree of correlation between the two instruments. Measurements could be made more quickly with the distortion analyzer, but specific information on the harmonic content of the signal was available from the spectrum analyzer.

Summary

Harmonic distortion measurements of signals from audio frequencies to the gigahertz range can be made by spectrum analyzers. In the audio range, measurements can be made more quickly using a distortion analyzer. However, if a distortion analyzer is unavailable, or if you need a detailed picture of the harmonic content of the signal, a low-frequency analyzer such as the TEKTRONIX 5L4N or 7L5 provides an excellent answer. A further advantage of the spectrum analyzer is the capability to provide "proof of performance" photos to the customer who requires them.

An application note describing the use of a low-frequency spectrum analyzer to perform standard audio tests is available from Tektronix.

New Products
New Products
New Products

Triservice 100-MHz Standard Oscilloscope

A 100-MHz Portable Oscilloscope designed to military specifications is now available to the commercial market. The TEKTRONIX 465M is the triservice 100-MHz standard oscilloscope (AN/USM 425) and is manufactured to meet the MIL-T-28800A, Type II, Class 4, Style C requirements.

With 100 MHz bandwidth at 5 mV/div sensitivity, variable trigger holdoff and delayed sweep, the 465M dual-trace portable is packaged in a rugged, mar resistant, reinforced plastic case.

The clearly-labeled controls, color coding, and functional group arrangements minimize operator training time.

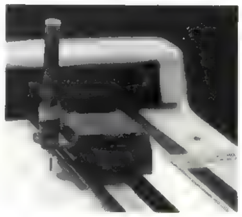
Since the military catalogs all parts for the military version (AN/USM 425), parts provisioning and logistics support are not problems when specifying the 465M as test equipment in military applications.

Versatile, General-Purpose Equipment Cart

The TEKTRONIX Rack Cart Model 7 is a new versatile and rugged equipment cart designed to accommodate standard 19-inch rackmounted systems.

Computers, small systems, or test centers can be assembled into this mobile test unit. Equipment can be mounted facing either to the front or rear; and the side panels are removable for easy access to the interior of the cart. Special safety belts allow an oscilloscope to be mounted on the top of the cart.

The lightweight Model 7 is designed and UL listed to carry up to 300 pounds of equipment (200 lbs inside and 100 lbs on top). The Model 7 may be shipped with up to 200 pounds of equipment mounted inside.



Accessories Expand Digital Plotter Usefulness

Several new accessories are available that offer new capabilities and/or operating convenience to 4662 Digital Plotter users. A new series of felt-tip pens offer you the ability to produce high-quality overhead projection slides in your choice of nine colors. Slide-maker programs are available for use with the 4051 and with TCS and 4662A01 subroutines.

All current-production 4662s accommodate wet-ink pens for making multicolored plots. Older 4662s may be updated to accept the wet-ink pens by ordering a new pen holder, which takes about one minute to install.

A new pedestal is convenient for the 4662 when desk top space is at a premium. Rollers on the back provide for easy movement, and a stable platform while the plotter is in use.

If your application calls for carrying your 4662 from place to place, a carrying case with rollers on the bottom makes for easy transport, while preventing physical damage to the pen assembly. The case has been designed

to carry the plotter plus cables, paper, pens, etc.

A foot-pedal-operated remote call switch provides a convenient means of inputting pen coordinates for digitizing plots, and other GIN functions.

ROM Expander Increases 4051 Versatility

The 4051E01 ROM Expander unit increases the number of plug-in ROMs and plug-in interfaces that can be used with a 4051. Up to nine ROMs can be accommodated in the 4051 with one ROM Expander, and up to 16 ROMs with two.

Multiple RS-232 output ports and multiple parallel interface devices are now supported by the 4051. 4051-E01 adds interrupt capability to the backpack slots of the 4051; previously interrupts were supported only by the GPIB.

Local Interactivity Available for TEKTRONIX 4014 Terminals

Tektronix has announced an Interactive Buffer for the TEKTRONIX 4014 and 4015 Computer Display Terminals. The Interactive Buffer provides 1023 characters of local storage which can be used for storing or refreshing graphic or alphanumeric information. These refreshed objects, such as a special design or map symbol, may then be moved over a complex background, with the thumbwheels or an optional joystick, and the new locations sent back to the host computer. Detailed plots may be easily composed from simple moveable and storable picture elements.

The buffer may also be used for buffered communications and limited editing of a line of alphanumeric data. Characters displayed from the buffer may be corrected by backspacing and retyping [illegible]. This allows adding or changing labels on yo[illegible]

New 650A-Series Color Picture Monitor

The 650A Series is designed for use in exacting applications where picture quality is particularly important. Designed for stability and simplicity of convergence, this monitor produces a consistently sharp, geometrically accurate picture.

Picture sharpness in the 650A Series is enhanced by variable aperature correction. You can choose the amount of correction desired, with a continuously-variable front-panel control. The control has a detented position that is factory preset for optimum display of the vertical crosshatch lines.

The unique BLUE ONLY mode ties the blue drive signal to the red, green, and blue channels simultaneously. This provides a monochrome display with a high sensitivity to VTR problems, such as unequalized head amplifiers that cause banding in the picture.

New Probes Expand Measurement Capability

Several recent additions to the modular probe family offer new measurement capability and convenience. The P6420 RF Probe converts dc voltmeters into high-frequency ac voltmeters by producing a dc output voltage equal to the rms value of a sine wave input. Designed to be used with digital multimeters which have 10 MΩ inputs, such as the TEKTRONIX DM 44, DM 501, DM 502, and 7D12/M1, the P6420 measures ac voltage from 10 kHz to 1 GHz.

Two new 1X-10X passive probes, the P6062B and P6063B, with bandwidths of DC to 100 MHz and DC to 200 MHz, respectively, allows the user to conveniently switch a decade of sensitivity without returning to the oscilloscope. The 1X-10X switch is located on the probe body, along with a ground-reference button that also serves as a convenient trace identifier.

The new P6106 is a 300 MHz, 10X passive probe for dc-to-350 MHz scopes with inputs of 1 MΩ and 15 to 24 pf. It, too, has a ground-reference button on the [illegible] body.

A-3654

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